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Starch deposition in the sporogenous cells of certain mosses

ROBERTA MOHLING MA

(WITH PLATE 31)

Since special protein bodies which serve as primordia of starch grains are present in the large single plastids of several of the fern allies, the writer has been led to think that in the single chloroplasts of the sporogenous tissue of the Bryales a similar condition may exist.

Sapĕhin (1911, 1915) seems to have been the first to describe the large single plastids in the sporogenous tissue of the mosses. He states that, due to cessation of the division of the plastids in cells in this region of the moss capsule, the cells of the single archesporial layer come to have a single plastid each. By the division of this plastid, the cells of the sporogenous tissue each receive a single plastid. Sapĕhin states that this is characteristic of all the Bryales. His principal interest in these single plastids is to show the continuity of the plastid throughout the life cycle of the mosses. His conclusions are that these chloroplasts, and the chondriosomes, which are also present, are individual and independent structures of the cells. He is positive that the chondriosomes do not give rise to the plastids at any time in the life cycle of the mosses.

Senjaninova (1928) has studied the plastids and chondriosomes of the sporogenous layer in *Catharinia* and *Physcomitrium:* she believes that the plastids disappear from the archesporial cells at or about the time of the differentiation of these cells. She describes numerous chondriosomes of various shapes as occurring in the archesporial cells. They, together with some of the cytoplasm, aggregate to form an irregular saucer-shaped structure curving about the nucleus. Senjaninova regards this structure as a complex plastid in which elongated starch grains may be seen. She believes that these bodies undergo segmentation to form the plastids of the sporogenous cells and spores.

The chloroplasts of *Isoetes* and of *Selaginella*, as described by the writer (Ma, 1928, 1931), contain red-staining pyrenoid-like bodies and also starch grains. The single, large chloroplasts of the cells of the young leaves, when stained with Flemming's triple stain, show contents similar to those of the plastids of *Anthoceros* and *Notothylas* (McAllister, 1914, 1927). The bodies in the plastids of *Isoetes* are rounded and those in *Selaginella* are spindle-shaped. Red-staining bodies may be seen in the plastids of the younger cells and blue-staining in the older. In plastids of intermediate

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age sometimes both kinds of bodies are present. They are similar in size and shape. These phenomena have led the writer to conclude that, as in the case of *Anthoceros* and *Notothylas*, the red-staining bodies found in *Isoetes* and *Selaginella* are primordia of starch grains.

Out of a total of seventeen different mosses examined, four species, whose plastids are relatively large and their contents easy to distinguish, were selected for intensive study. These species are *Atrichum undulatum* Beauv., *Bryum argenteum* Linn., *Funaria americana* Lindb., and *Physcomitrium turbinatum* Müller.

Merkel's fluid, as repeatedly experienced, proved to be the most satisfactory fixing agent for the study of chloroplasts and their contents. For the purpose of studying the chloroplasts and of differentiating the blue-staining starch grains and the red-staining bodies in the plastids, Flemming's triple stain was used almost exclusively. This stain gives a blue color to the starch grains, red to pyrenoid bodies, and yellow to the plastids and the surrounding cytoplasm. Heidenhain's iron-alum-haematoxylin stain was used as a check on the red-staining bodies.

ATRICHUM UNDULATUM BEAUV.

The cells in the single archesporial layer in *Atrichum* divide twice, usually forming four layers of sporogenous cells. These cells range from 5 to 10 microns broad and from 6 to 17 microns long. The plastids are shaped like a thick concavo-convex lens. In median sections, cut parallel with the radius, they appear as elongated, kidney-bean-shaped structures, curving about the nucleus. They are clearly recognizable in all of the cells of the archesporial and sporogenous layers.

In very young archesporial cells the plastid contents are not as distinct as those of the older cells. Red-staining bodies are nevertheless recognizable at this early stage and seem to be rounded in shape (fig. 1). As the young archesporial cell grows larger the red-staining bodies become elongated, spindle-shaped structures (figs. 2, 3). Blue-staining bodies are usually not recognizable in young plastids, though some plastids contain bodies intermediate in color between blue and red (fig. 3). After the first division of the archesporial cells the plastids contain slender, spindle-shaped bodies which are usually all red-staining (fig. 2), though occasionally some plastids may contain both red- and blue-staining bodies of the same size and shape (fig. 4). When the four layers of sporogenous cells have been formed, the plastids usually contain only blue-staining starch grains (figs. 5, 6).

BRYUM ARGENTEUM LINN.

In *Bryum argenteum*, as in *Atrichum*, the single archesporial layer develops into four layers of sporogenous cells. The sporogenous cells average about 12 microns long and 8 microns broad. These cells contain a single, large plastid (figs. 7, 8, 9), though occasionally there are two plastids in a cell (fig. 10). The presence of two plastids in a cell is probably due to the division of the plastid preceding nuclear and cell division. No archesporial or sporogenous cells were observed which did not contain definite, well differentiated plastids. The plastids are usually shaped like a bowl with a thin wall and a very thick base. They lie with their concave sides close to the nucleus (fig. 10).

The plastids of the sporogenous cells of *Bryum* contain red-staining bodies and blue-staining starch grains, as has been noted for *Atrichum*. These bodies lie in the thickened base of the bowl-shaped plastid. They vary in size and staining reaction according to the age of the tissue. In cells of the archesporial layer only red-staining bodies are seen (fig. 7). They are so minute that their exact outlines are difficult to distinguish. As the archesporial cells increase in size, the bodies become larger and their outlines more definite. They are then seen to be distinctly spindle-shaped (fig. 8). By the time the sporogenous tissue has become two-layered, the plastids of these cells show only spindle-shaped starch grains (figs. 9, 10). They are similar in size, shape, and approximate number to the red-staining bodies previously mentioned for the younger cells.

FUNARIA AMERICANA LINDB.

Funaria americana also has four layers of sporogenous cells. These cells measure 5 to 10 microns in width and 10 to 12 microns in length. They are thin and bowl-shaped, with the nuclei lying in the concavity (figs. 11, 12, 13). Since meiosis follows the last division of the sporogenous cells so closely, the plastids of the spore mother cells are small and their outlines hard to distinguish. The plastids lie opposite the equatorial region during metaphase and anaphase of meiosis (fig. 14).

The plastids of the sporogenous cells of *Funaria*, as is the case in *Atrichum* and *Bryum*, contain red- and blue-staining bodies. These bodies are slender-spindle-shaped. The plastids of the archesporial layer usually contain slender, red-staining, spindle-shaped bodies only (fig. 11). When the sporogenous tissue becomes two layers of cells in thickness, the plastids of these cells contain blue-staining starch grains, similar in shape and size to the red-staining bodies of the younger cells (figs. 12, 13).

PHYSCOMITRIUM TURBINATUM MÜLLER

Although numerous capsules of *Physcomitrium turbinatum* have been examined, none show sporogenous tissue having more than one layer of cells. As these cells differentiate into spore mother cells they increase conspicuously in size. As a result of this growth the spore mother cells are much larger than the sporogenous cells. The latter cells average 10 microns in their shortest dimension and 18 microns in their longer. The spore mother cells are roughly spherical and have an average diameter of about 26 microns.

The plastids, which are always present in the archesporial and sporogenous cells, are shaped like a thin, shallow bowl. Some plastids contain slender, spindle-shaped, red-staining bodies, and other contain blue-staining bodies of similar size and shape.

Since the spore mother cells of *Physcomitrium* are unusually large, the plastids are proportionately large. They are many times larger than the plastids of the archesporial cells. They are, in general, shaped like a thick concavo-convex lens. The nuclei always lie in the convavity of the plastids, in close proximity to them. In the early prophase of the first meiotic division the plastids divide and the two halves pull away from one another to occupy positions at opposite sides of the nucleus (figs. 15, 16). During anaphase the plastids lie at the sides of the narrow spindle (fig. 19). The plastids divide once more and each spore receives one.

Due to the unusually large size of the spore mother cells, their plastids and contents have been especially favorable for study. The plastids contain rounded blue- and red-staining bodies instead of the spindle-shaped bodies found in plastids of the sporogenous layers of all of the mosses studied. In some plastids only red-staining bodies are to be found. In others the red-staining bodies are mixed with blue-staining starch grains of similar shape and size (fig. 15). In still others there are only blue-staining starch grains (figs. 16, 18, 19, 20). These red-staining bodies and the starch grains are similar in size and shape. The red-staining bodies greatly resemble the pyrenoid bodies which are often mingled with starch grains in the plastids of the spore mother cells of *Anthoceros* and *Notothylas* as described by McAllister (1914, 1927).

As in the sporogenous cells, the plastids of the spore mother cells are flattened structures. When the plastid divides, the two halves are, for a time, connected by a broad, thin, band of plastid material (figs. 16, 17, 20). In this band, conspicuous fibers are to be seen, especially during the division of the plastids in the spore mother cells. These fibers form a skein between the two halves of the dividing plastid (fig. 17). The general ap-

pearance of this skein of fibers is much like that of neighboring anaphase spindle figures, so that with a casual examination one may easily mistake one for the other. The fibers are very similar in size, texture and staining reaction to those of adjacent homeotypic figures. Both the fibers of the nuclear figure and those of the dividing plastids stain a reddish violet and lie in a yellowish-staining ground substance. They are often thick in the central region and gradually thinner at the ends, blending into the body of the plastid halves.

Phenomena of the same sort as that just described were probably first reported by Von Mohl (1839) in his classic paper on spore development in *Anthoceros*; he, however, described and illustrated the fibrous skeins as connecting all four plastids in the spore mother cell (figs. 21–23). Somewhat similar figures of *Anthoceros* were published by Strasburger (1880). The fibrous skeins were apparently not seen in the preparations of Davis (1899), but have been mentioned briefly in the recent work of Pinnick (1926), who, however, has ignored Von Mohl's account, which seems to have been unknown to Davis also.

SUMMARY AND DISCUSSION

In accordance with the observations of Sapĕhin (1911, 1915), the writer has found that the sporogenous cells of the mosses studied contain a single large, shallow bowl-shaped plastid. The plastids of *Atrichum undulatum*, *Bryum argenteum*, *Funaria americana* and *Physcomitrium turbinatum* also resemble those of *Selaginella apus*, as well as the chloroplasts of *Anthoceros* and *Notothylas*.

The disappearance of the single plastid in the archesporial cells and the subsequent formation of a new plastid from a mass of chondriosomes as described by Senjaninova (1928) has not been confirmed. A well-defined plastid is always present in these archesporial and sporogenous cells of the mosses studied.

When the material is treated with Flemming's triple stain the plastids show red- or blue-staining bodies or both. Those of very young cells of the archesporium of *Atrichum* for example contain only red-staining and rounded bodies, indistinct in outline. As the cells become older these bodies become spindle-shaped. In the plastids of all the archesporial cells and in some of the early sporogenous cells red-staining bodies only are present. However, many of the plastids of the sporogenous cells show starch grains of the same size and shape as the red-staining bodies. Plastids of two adjacent cells often show red-staining bodies in the one and starch grains in the other. In *Atrichum* one often finds both red-staining bodies and starch grains in the same plastid. These bodies are similar in shape, size,

and location, and differ visibly only in the color reaction. The red-staining bodies of the sporogenous cells of the four mosses studied resemble in shape and chemical reaction the red-staining bodies of *Selaginella apus*. They are likewise similar to the pyrenoid bodies of the gametophytes of *Anthoceros* and *Notothylas* (McAllister, 1914, 1927). In all these plants the red-staining bodies have the same relation to the starch grains which replace them. Because of their close relation to starch deposition it is probable that they should all be called 'pyrenoid-bodies' or simply 'pyrenoids.'

In the plastids of the spore mother cells of these mosses red- and blue-staining bodies are present, differing only from those in the sporogenous tissue in that they are spherical instead of spindle-shaped. The red-staining bodies are gradually replaced in the older cells by starch grains of similar size and shape to the pyrenoid bodies. They resemble in shape and chemical reaction the red-staining bodies and starch grains in the plastids of *Isoetes melanopoda* and those of the spore mother cells of *Anthoceros* and *Notothylas*. McAllister has shown that the red-staining, rounded bodies of the spore mother cells of *Anthoceros* and *Notothylas* are in chemical reaction and function similar to the spindle-shaped pyrenoid bodies in the plastids of the gametophytes. This difference in the shape of the pyrenoid bodies and starch grains in somatic and spore mother cells must be due to the surroundings of the latter cells. The spore mother cell lies free in a liquid substratum, and seems in its younger stages to lack definite polarity. This lack seems to be reflected in the cell activities and the form of the cell organs.

Since both in sporogenous tissues and in spore mother cells the red-staining bodies are replaced by starch grains similar to them in size, shape, and approximate number, we must conclude that either the former bodies are transformed into starch grains or that they disintegrate and that starch grains arise *de novo*.

It would indeed be a striking coincidence if one set of bodies should entirely disappear and be replaced by a new set of bodies, similar in size and shape and having the approximate number and location of the former, and this replacement following immediately upon the disappearance of the former. In the absence of any evidence of the disintegration of the pyrenoids we must conclude that they are transformed into starch grains. The conclusion that the pyrenoid bodies are primordia of starch grains seems amply justified.

Plastids of the vegetative cells of the mosses are small and numerous and their finer details are difficult to distinguish, even with the highest magnification. Still we must believe that in these small plastids starch de-

position is chemically and physiologically the same as in the large single plastids of the sporogenous layers. In the older cells of the leaves of *Isoetes*, in which there are as many as thirty plastids to the cell, the plastid contents are similar to those of the large single plastids of the young cells. Minute red- and blue-staining bodies are present. It is probably true that a similar condition exists in the mosses, and that the numerous small plastids of the vegetative cells have red-staining starch primordia too minute to be recognized with certainty.

The presence of fiber-like structures during the rapid division of the plastids in the spore mother cells of *Physcomitrium* seems to be of considerable significance. When division of these plastids is nearly completed, the two halves are connected by a broad, thin isthmus of plastid material. At this stage the colloidal protoplasm must be flowing rapidly into the halves of the dividing plastid. This movement, which is much more rapid than in vegetative plastids, is shown in the fibrous appearance after fixation. The similarity of the skein-like connecting band between the plastid halves to spindle figures in neighboring mother cells is very striking. The general appearance, as well as the staining reaction and texture of the fibers, is almost identical in the two cases. It is easy to confuse the two structures if examined hastily. It seems impossible to avoid the conclusion that the two structures have arisen from similar physiological conditions. That the spindle figure is due to some sort of protoplasmic streaming has been repeatedly suggested. These spindle-like structures in dividing plastids give additional support to this view.

This work was completed in the botanical laboratories of the University of Texas, and the writer makes grateful acknowledgment to Professor Frederick McAllister for continued assistance and encouragement.

YENCHING UNIVERSITY
PEIPING, CHINA

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Explanation of plate 31

All drawings have been made with the aid of a camera lucida. The original magnification of figures 1–14 was 2300 times; of figures 15–20, 1700 times. This magnification has been reduced about one-fifth in reproduction.

Fig. 1. Cell taken from very young archesporium showing indistinct rounded red-staining bodies. *Atrichum.*

Fig. 2. Cell from sporogenous tissue showing single plastid containing distinct spindle-shaped red-staining bodies. *Atrichum.*

Fig. 3. Slightly older cell from sporogenous layer viewed from inner surface, showing spindle-shaped bodies in transition from red-staining to blue-staining. *Atrichum.*

Fig. 4. Sporogenous cell with two plastids; spindle-shaped bodies partly blue-staining and partly red-staining. *Atrichum.*

Fig. 5. Still older sporogenous cell with conspicuous starch grains. *Atrichum.*

Fig. 6. Cell from two-layered sporogenous layer showing nuclear division and plastids with starch grains. *Atrichum.*

Fig. 7. Cell from young archesporium showing single bowl-shaped plastid containing red-staining bodies which are becoming spindle-shaped. *Bryum.*

Fig. 8. Cell from single-layered sporogenous tissue. *Bryum.*

Fig. 9. Cell from older sporogenous tissue with large, thick plastid and conspicuous starch grains. *Bryum.*

Fig. 10. Cell with two plastids and abundant starch. *Bryum.*

Fig. 11. Cell from young sporogenous tissue showing thin plastid and spindle-shaped red-staining bodies. *Funaria.*

Fig. 12. Cells from similar tissue showing plastids with starch grains. *Funaria.*

Fig. 13. Two cells soon after the completion of cell division. *Funaria.*

Fig. 14. Early anaphase of meiosis showing plastids with rounded starch grains. *Funaria.*

Fig. 15. Spore mother cell showing two plastids which contain rounded red- and blue-staining bodies. *Physcomitrium.*

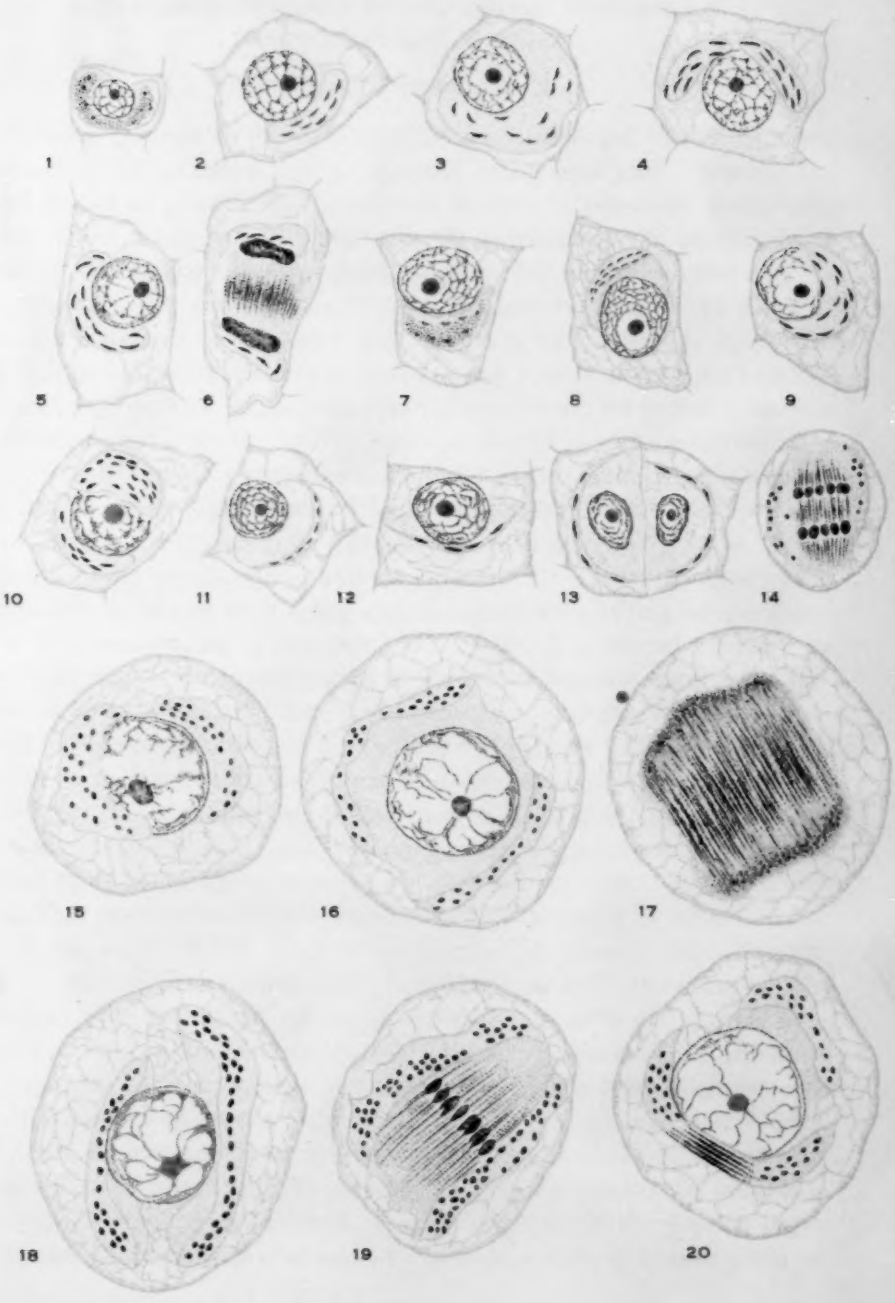
Fig. 16. Spore mother cell showing dividing plastid, the two parts of which are not quite separated from one another. *Physcomitrium.*

Fig. 17. Same cell as shown in figure 16 at a different focus, showing the connecting band of fibrous material. *Physcomitrium.*

Fig. 18. Spore mother cell showing two plastids with conspicuous rounded starch grains. *Physcomitrium.*

Fig. 19. Metaphase of first reduction division; showing large plastids. *Physcomitrium.*

Fig. 20. Spore mother cell showing second division of plastids; a spindle-like structure connecting the two parts of the plastid. *Physcomitrium.*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Daily periodicity of growth in the bamboo, Phyllostachys nigra, with special reference to atmospheric conditions of temperature and moisture

WILLARD M. PORTERFIELD, JR.

Periodic changes in external conditions are reflected in the recurrent alternations of retarded and accelerated plant functions. During the grand period of growth this correlated rhythm is especially noticeable. Sachs (1874) made it quite clear that in considering the conditions of growth it is necessary to distinguish between day and night, not only by the mere presence and absence of light but also because of the effect of alternating periods of light and darkness on temperature and humidity. The differential relation between the opposing factors of daylight retardation and day-warmth acceleration partially accounts for periodic changes in growth-rate during the twelve hours of daylight, while a similar relation exists with equally varying results between the falling night-temperature and the rising night-humidity factors during the twelve hours of darkness. Of the conditions most affecting the rate of growth, Sachs stated further that temperature fluctuations outweigh all others. In general the growth-rate increases with rising and decreases with falling temperature.

In previous papers (Porterfield, 1927, 1928) I produced evidence to show that during the grand period of growth of bamboo shoots[1] the factor most directly affecting the rate of growth is temperature. I called attention to the fact that while the records of humidity generally showed a drop at times when the growth-rate recorded was higher than usual, the temperature, on the other hand, had risen in all of these cases and therefore was to be considered positively the most effective influence. I brought forward some data with reference to day and night growth-rates which suggested that the bamboo shoots under consideration grew faster in the day than in the night. While temperature only in conjunction with other factors can be said to determine daily periodicity as such, the curves of the periodical rates published by me in those papers certainly showed synchronic variations which undoubtedly were due to external conditions of temperature. As the records furnished only averaged readings for each day, the conditions at the different periods of the day were not known, and hence no connection between the variations in the diurnal and nocturnal rates of growth and the external factors of temperature, humidity, and rainfall could be established. I shall introduce in the present paper additional measurements of shoots of *Phyllostachys nigra* Munro made re-

[1] *Phyllostachys nigra* and *P. quadrangularis*.

cently with special reference to periodic growth during the day, together with specific thermic and psychrometric readings. These will determine the relation, if any, existing between external conditions and the daily periodic growth-rates of bamboo shoots.

REVIEW OF LITERATURE

The literature on the growth of bamboos furnishes only scant evidence on the subject of the daily periodicity of growth. As I have reviewed the literature on the growth of bamboos more fully elsewhere, I shall include here merely a sketch of that part which deals more particularly with daily periodicity of growth.

Hofrath von Martius (1848) reported the measurements of *Bambusa* (*Dendrocalamus*) *gigantea* Wall., *B. Balcoa* Roxb., and two other species made in 1833 by Hindus working in the Calcutta gardens. Shoots of *B. gigantea* were measured twice daily for the 31 days of July and those of *B. Balcoa* for 23 days in the same month. No tabulations appear in the report, no mention is made of the hour at which measurements were made, and no statement is made of the external conditions under which the shoots were growing. The sum total of daily increments in the former species was less than that of the nightly gain, a fact which showed greater growth by night. On the other hand, in the latter species the daily increments amounted to more than those of the night.

A. and C. Rivière (1878) paid very careful attention to daily periodicity in the growth of their bamboos in Algiers. The measurements tabulated were in terms of increments of four categories: those accruing from 6 a.m. to 12 noon, from 12 to 6 p.m., from 6 p.m. to 6 a.m., and the total increment for the day (24 hours). In other words, not only day and night growth but elongation during the daily periods of forenoon and afternoon also was studied. Moreover, thermic and psychrometric conditions were noted. The complete records of these, however, are not published, so that it is difficult to compare the variations in growth-rate with the fluctuations of temperature and humidity. In the three autumn-growing types, *Bambusa macroculmis* A. & C. Riv., *B. vulgaris* Wendl., and *B. vulgaris* var. *vittata* A. & C. Riv., without exception the total gain in the afternoon was greater than that made in the forenoon, and the night growth was greater than the day growth. On the other hand, the spring-growing forms, *Phyllostachys nigra* Munro, *P. aurea* A. & C. Riv., and *P. viridi-glaucescens* A. & C. Riv., including a young shoot of *P. mitis* A. & C. Riv., all showed greater growth during the day. Of these *P. mitis*, *P. nigra*, and one shoot of *P. viridi-glaucescens* showed greater afternoon elongation, while *P. aurea* and the second shoot of *P. viridi-glaucescens* showed greater morning

growth. Another shoot of *P. nigra* measured for eleven days through the period of most rapid elongation appears also to have grown faster in the morning than in the afternoon. An older shoot of *P. mitis*, though exhibiting greater total afternoon elongation, showed greater night growth as compared with the morning, contrary to what was found to be the case of the younger shoot. An interesting observation made by the Rivières is that, although the total afternoon growth is greater than that of the morning, there is a larger number of individual cases in which the forenoon growth is greater. Thus, in the table of growth increments for *P. nigra* in Algiers, the gains for twenty-five days are recorded, of which thirteen show less growth in the afternoon than in the morning, eleven greater growth in the afternoon, and one the same in both. The total for all the days, however, showed a balance in favor of afternoon growth. Because of the number of cases observed in which under similar conditions diverse results in the rate of elongation have been recorded—i.e., cases in which the relation between day and night growth and also that between the forenoon and afternoon periods have been reversed in the same species under the same conditions, e.g., *P. mitis*, *P. nigra*, and *P. viridi-glaucescens*—the Rivières disclaim any influence of external conditions on the growth of bamboo shoots generally.

Kraus (1895) in Java measured two shoots of *Dendrocalamus giganteus* Munro three times a day from December 4 to 10 at 6 a.m., 12 noon, and at 6 p.m. In 16 cases with a single exception growth in the twelve hours of night was regularly greater than by day in the ratio of 1.8:1. The conditions were very constant. There was rain every day for two months except for five days and the temperature varied regularly every day between 23° and 32°C. Kraus remarks that under such conditions, if the curve is irregular, the causes must certainly be other than climatic. On December 4 shoot no. 1 grew 15.4 mm. in the day but only 12.4 in the night. On the other hand, shoot no. 2 grew 8.8 in the day and 13.3 mm. in the night, a difference of 4.5 mm. in favor of the night. On December 8, 65 per cent of the day's growth of no. 1 was made in the night, while that made by no. 2 at the same time was 52 per cent. Irregularities and lack of parallelism in growth-rate Kraus ascribes to internal factors.

Lock (1904) in Ceylon measured shoots of *Dendrocalamus giganteus* Munro, together with several of *Gigantochloa aspera* Kurz and *Bambusa spinosa* Roxb. Measurements were made twice daily at 7:30 a.m. and 5:30 p.m. from June 19 to July 18. The records of two shoots were tabulated in terms of growth per hour for day and night, together with the height of the shoots at the time of measurement. The ratio of night to day growth in both shoots was approximately 3:1. Records for seven days of

measurements were made for two shoots of *Gigantochloa* and these yielded very much the same ratio of night to day growth. Hourly measurements taken of two shoots of *Dendrocalamus* from June 22 to 23 and again from June 28 to 30 showed in each case a rise of growth-rate to a maximum shortly after dark and a fall at daybreak. The values of the morning and of the afternoon growth-rates appear to be nearly the same. Lock specifically states from his experience that the variation of growth-rate during the day showed a marked parallelism with changes of weather. As to the climatic conditions under which the shoots were growing, he says also that the temperature was very constant, the range for June, July, and August being from 19° to 30° C., and half of the time from 21° to 25° C. On the other hand, sunlight, rainfall, and moisture of the air varied considerably. A strong wind was rare. In his discussion Lock, noting the great importance of moisture for growth and the regular daily change from dry air by day to moist air by night, concludes that it is 'highly probable that periodicity of growth may be found in other cases to be connected with periodic changes of moisture.' Curves of hourly growth together with the curves of temperature, humidity, and rainfall appear with this account.

Osmaston (1918) in India at Dehra Dun measured seventeen shoots of *Dendrocalamus giganteus* twice a day at 6 a.m. and at 6 p.m. from August 19 to September 11, though growth did not cease until the end of November. These measurements showed that growth at night was twice as rapid as that in the daytime. This difference in rate of growth, according to Osmaston, has nothing to do with light, nor is it directly connected with temperature. The maximum growth was reached when the humidity was highest. Nothing was stated as to the relation of morning to afternoon growth.

Galloway (1925), in his allusion to the phenomenal growth of *Phyllostachys bambusoides* Sieb. & Zucc. at the Chico Plant Introduction Gardens in California, U. S. A., mentions the fact that greatest elongation usually took place in the daytime. No tables, no records of climatic conditions, and no discussion of daily periodicity are included in his account.

Of my own previous work on the growth of bamboos (Porterfield, 1927, 1928), in which I referred to the daily periodicity of growth, I have already written. Beyond these papers I find no other works dealing with the daily growth periodicity of bamboo shoots.

METHODS

The present investigation was carried out on the campus of St. John's University, Shanghai, China, in the spring of the year 1929. Eighteen

shoots of *Phyllostachys nigra* Munro were selected for measurement as they appeared, beginning on April 22. Measurements were made twice daily, 6 a.m. and 6 p.m., up to May 1, from which time they were made three times each day, the third time being at 12 noon. These were continued to May 11. By May 13 elongation in most cases had slowed up so that for the purpose of the investigation further measurements were unnecessary. The methods of measuring and of tabulation were the same as those used in my previous study of the grand period of growth (1928). The amounts of the day and night gain (see table 1), which in each case represent the gain of the period just preceding, appear together with those for the total height. Table 2 (appendix) contains the measurements made three times a day, accompanied by the gains made during the hours of 6 a.m. to 12 noon, 12 to 6 p.m., and 6 p.m. to 6 a.m. The meteorological station at Sicawei nearby kindly supplied the specific readings for the temperature, humidity, and rainfall. There are four readings for every day as follows: at 4 and 9 a.m. and at 4 and 9 p.m. These have been tabulated separately in table 3. In order more convincingly to show relationship between the daily growth periodicity and external conditions, the curves of daily growth were constructed from the data in table 1 together with those representing the periodical fluctuations in temperature, humidity, and rainfall. The curves of shoots 1, 3, 6, and 7 appear in figure 1. The same method was employed with the data in table 2, but here as in the previous case, owing to lack of space, the curves of shoots 1, 3, 5, and 6 only were plotted in figure 2.

With each shoot the predominance first of day growth over night growth, then of afternoon over forenoon growth was figured as percentage of total elongation; likewise the average percentage relationship of the whole lot was calculated. Day gains for each shoot were first added, then the night gains. The sum of the two gave the total increment. The sum of the totals for the day gain of all the shoots plus that for the night gain equal the sum of the total increments. From this was found the average percentage predominance of day over night growth, and in the same way afternoon over forenoon growth. In both problems the figures necessarily appear in sets, i.e., pairs. Odd figures obviously could not be included in the total as they would upset the balance of relationship. This is the reason that in the tables the unpaired figures are bracketed. In table 1 a set of figures comprises first the daytime increment, followed by the nighttime increment. In table 2 a set of figures comprises a forenoon, followed by an afternoon increment. The figures for the night gains in both tables are the same for the same period of time.

OBSERVATIONS

Before trying to relate the rates of growth to the climatic environment of the plants, I shall first describe the conditions under which the shoots were growing. The curves in figure 1, showing the daily oscillations of tem-

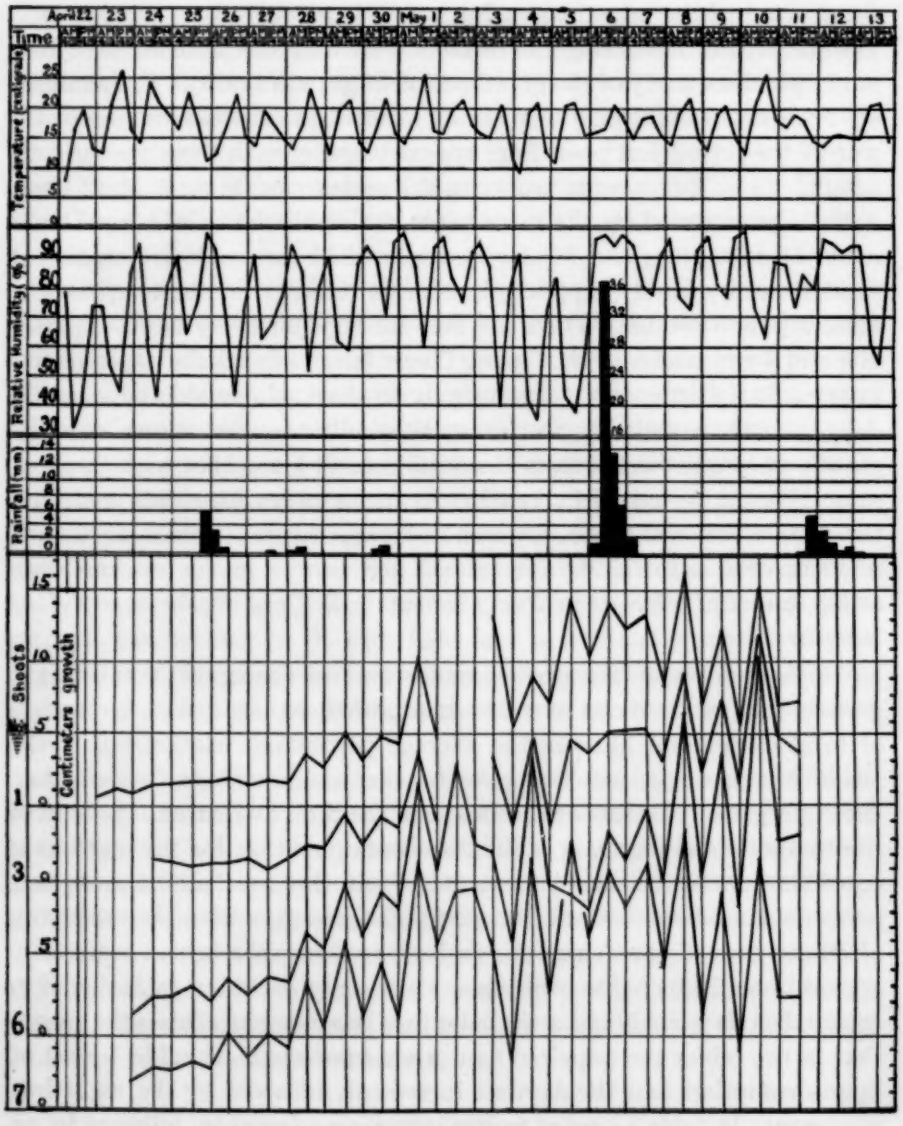

Fig. 1. Shoots 1, 3, 6, and 7 of *Phyllostachys nigra*. The curves of night and day growth, together with those of temperature, relative humidity, and rainfall, for 22 days, April 22–May 13.

perature, humidity, and rainfall, give an accurate picture of conditions during growth.

Temperature. The temperature was found to vary between 7.6° and 23.3° C. with an average daily fluctuation range of 9°. Some days (April 23 and May 10) showed as much variation as 14°, while others (May 7 and 12) showed as little as 2°. In general the temperature follows a regular course daily. It rises in the morning, reaches a maximum in the afternoon, then sinks rapidly with the setting sun to a low level, which is lowest around four o'clock in the morning. The average high point at 4 p.m. was 22° and the average low point at 4 a.m. was 14°C. On April 24, 25, 27, and May 11 the maximum temperature for the day occurred in the morning, while on April 25 and May 5 the lowest point was reached in the earlier part of the night. These were the only exceptions to the general trend.

Humidity. The humidity follows a course opposed to that of the temperature. When the temperature rises during the day, the relative humidity sinks, but rises at night when the temperature drops. The total range of fluctuation was from 32 to 100 per cent, the largest single change in a day being 60 per cent, a rise from 38 per cent at 4 p.m. May 5 to 99 per cent at 9 a.m. the next day. The average high value at 4 a.m. was 93 per cent, and the average low value at 4 p.m. was 60 per cent, giving an average daily oscillation of 33 per cent. With the exception of April 22, 25, 27, and May 11 the lowest point reached by the humidity during the day was at 4 p.m., whereas the highest was generally reached about 4 a.m. As regards the degree of rise and fall of the humidity there exists distinct correlation with the changes of temperature. Thus, on the night of April 25 an unusual fall in temperature was balanced by an exceptional rise in humidity; a slighter rise in temperature during the day of April 27 was accompanied by a comparatively slight drop in humidity; a sharp rise in temperature on May 1 was balanced by a marked drop in humidity. Again a small rise in temperature on May 2 was offset by a correspondingly slight lowering of the humidity at the same time. A similar situation arose on May 9. During the following night a great drop in temperature occurred simultaneously with an unusual rise in humidity. During the next day (May 10) the humidity sank to an exceptionally low level while the temperature rose to an unusually high point.

Rainfall. Of the twenty-two days recorded, rain fell on ten of them, the heaviest fall occurring on May 6 with 59.12 mm. When I say ten days of the twenty-two were rainy I mean that rain fell during a part of each of them. Only two of the ten were rainy for the entire day, May 6 and 12. The ten days grouped themselves into five rainy periods: April 25–26, 27–28, 30, May 6–7, and May 11–13. Thus the conditions of moisture are

TABLE 1

Measurements, in centimeters, of shoots of Phyllostachys nigra from April 22 to May 13, 1929, with special reference to day and night growth

DATE	1			2*			3			6		
	HEIGHT	DAY GAIN	NIGHT GAIN	HEIGHT	DAY GAIN	NIGHT GAIN	HEIGHT	DAY GAIN	NIGHT GAIN	HEIGHT	DAY GAIN	NIGHT GAIN
April												
22, 6 p.m.	2.0	—		2.0	—		—	—		—	—	
23, 6 a.m.	2.5		[0.5]	2.3		[0.3]	—		—	—		—
6 p.m.	3.5	1.0		2.8	0.5		—	—		10.5	—	
24, 6 a.m.	4.3		0.8	3.3		0.5	3.8		—	11.7		[1.2]
6 p.m.	5.5	1.2		4.0	0.7		5.1	1.3		14.0	2.3	
25, 6 a.m.	6.9		1.4	4.7		0.7	6.3		1.2	16.3		2.3
6 p.m.	8.5	1.6		5.8	1.1		7.2	0.9		19.3	3.0	
26, 6 a.m.	9.5		1.0	6.6		0.8	8.3		1.1	21.4		2.1
6 p.m.	11.4	1.9		7.6	1.0		9.5	1.2		25.0	3.6	
27, 6 a.m.	12.7		1.3	8.3		0.7	11.1		1.6	27.6		2.6
6 p.m.	14.4	1.7		9.6	1.3		12.0	0.9		31.4	3.8	
28, 6 a.m.	15.9		1.5	10.4		0.8	13.7		1.7	34.8		3.4
6 p.m.	19.2	3.3		12.3	1.9		16.0	2.3		41.7	6.9	
29, 6 a.m.	21.9		2.7	13.4		1.1	18.2		2.2	47.2		5.5
6 p.m.	27.0	5.1		15.4	2.0		22.6	4.4		57.2	10.0	
30, 6 a.m.	30.1		3.1	17.7		2.3	25.2		2.6	63.7		6.5
6 p.m.	35.0	4.9		20.0	2.3		29.4	4.2		73.0	9.3	
May												
1, 6 a.m.	39.3		4.3	21.7		1.7	33.0		3.6	81.2		8.2
6 p.m.	49.6	10.3		26.6	4.9		41.7	8.7		97.9	16.7	
2, 6 a.m.	54.5		4.9	30.0		3.4	45.7		4.0	108.8		10.9
6 p.m.	—	—		—	—		—	—		126.6	17.8	
3, 6 a.m.	73.7		—	38.5		—	58.4		—	139.2		12.6
6 p.m.	86.9	13.2		43.0	4.5		66.8	8.4		151.3	12.1	
4, 6 a.m.	92.5		5.6	45.0		2.0	70.5		3.7	156.6		5.3
6 p.m.	101.7	9.2		50.5	5.5		80.4	9.9		175.3	18.7	
5, 6 a.m.	109.1		7.4	53.5		3.0	84.1		3.7	185.2		9.9
6 p.m.	123.5	14.4		58.6	5.1		93.9	9.8		194.4	9.2	
6, 6 a.m.	134.2		10.7	63.6		5.0	102.5		8.6	202.6		8.2
6 p.m.	148.3	14.1		69.7	6.1		112.8	10.3		216.2	13.6	
7, 6 a.m.	160.8		12.5	74.2		4.5	123.3		10.5	227.6		11.4
6 p.m.	174.0	13.2		78.3	4.1		133.9	10.6		242.5	14.9	
8, 6 a.m.	182.5		8.5	81.1		2.8	142.0		8.1	252.7		10.2
6 p.m.	198.8	16.3		86.0	4.9		156.4	14.4		274.6	21.9	
9, 6 a.m.	206.2		7.4	88.2		2.2	163.8		7.4	284.9		10.3
6 p.m.	218.5	12.3		92.5	[4.3]		176.5	12.7		303.6	18.7	
10, 6 a.m.	224.1		5.6	—		—	183.3		6.8	312.2		8.6
6 p.m.	239.7	15.6		—	—		200.4	17.1		338.0	25.8	
11, 6 a.m.	247.0		7.3	—		—	210.5		10.1	351.0		13.0
6 p.m.	254.7	[7.7]		—	—		219.4	[8.9]		364.3	[13.3]	
12, 6 a.m.			—	—		—	—		—	—		—
6 p.m.	263.0	—		—	—		228.6	—		378.3	—	
13, 6 a.m.			—	—		—	—		—	—		—
6 p.m.	272.0	—		—	—		241.3	—		396.8	—	
Totals		139.3	86.0		46.9	31.5		117.1	76.9		208.3	131.0

* Undersized subnormal shoot. [—] Unpaired or odd measurement; therefore not included in totals.

seen to have varied through the growing period. In fact, no one of the three climatic factors considered showed any degree of constancy.

Growth. The observations of shoot elongation I shall divide into two parts: first, that dealing with the relation of day to night growth, and second, that dealing with the relation of forenoon to afternoon growth.

Study of table 1 reveals the fact that the sixteen shoots whose measurements appear all follow the manner of elongation previously described by me (1928), and that with few exceptions every day shows a greater gain in the daytime than at night. In the table 240 sets of figures in addition to those for height are recorded showing day and night increase for each day, of which 211, or 87.5 per cent, exhibit greater daytime growth, 23 greater night growth, and 6 the same amount of increase in both night and day.

TABLE 1 (Continued)

Measurements, in centimeters, of shoots of Phyllostachys nigra from April 22 to May 13, 1929, with special reference to day and night growth

DATE	7			8			9			10		
	HEIGHT	DAY GAIN	NIGHT GAIN	HEIGHT	DAY GAIN	NIGHT GAIN	HEIGHT	DAY GAIN	NIGHT GAIN	HEIGHT	DAY GAIN	NIGHT GAIN
April												
22, 6 p.m.	—	—		—	—		—	—		—	—	
23, 6 a.m.	—		—	—		—	—		—	—		—
6 p.m.	11.8	—		12.3	—		—	—		6.3	—	
24, 6 a.m.	13.6		[1.8]	14.5		[2.2]	—		—	8.5		[2.2]
6 p.m.	16.5	2.9		17.4	2.9		—	—		10.5	2.0	
25, 6 a.m.	19.2		2.7	20.8		3.4	—		—	13.0		2.5
6 p.m.	22.4	3.2		25.3	4.5		—	—		15.6	2.6	
26, 6 a.m.	25.2		2.8	27.8		2.5	—		—	17.6		2.0
6 p.m.	30.4	5.2		32.7	4.9		8.5	—		21.1	3.5	
27, 6 a.m.	34.0		3.6	36.0		3.3	10.5		[2.0]	23.6		2.5
6 p.m.	39.1	5.1		40.8	4.8		11.7	1.2		26.8	3.2	
28, 6 a.m.	43.3		4.2	44.8		4.0	13.2		1.5	29.6		2.8
6 p.m.	51.9	8.6		53.2	8.4		15.5	2.3		35.2	5.6	
29, 6 a.m.	57.6		5.7	56.0		2.8*	18.0		2.5	39.2		4.0
6 p.m.	68.7	11.1		66.8	10.8		21.6	3.6		47.2	8.0	
30, 6 a.m.	74.8		6.1	73.2		6.4	24.5		2.9	51.6		4.4
6 p.m.	84.4	9.6		83.1	9.9		28.3	3.8		58.4	6.8	
May												
1, 6 a.m.	90.5		6.1	91.3		8.2	32.6		4.3	63.9		5.5
6 p.m.	107.1	16.6		108.2	16.9		40.2	7.6		76.0	12.1	
2, 6 a.m.	117.8		10.7	120.8		12.6	46.1		5.9	83.1		7.1
6 p.m.	132.1	14.3		139.8	19.0		55.7	9.6		93.1	10.0	
3, 6 a.m.	146.7		14.6	152.6		12.8	62.9		7.2	102.2		9.1
6 p.m.	157.8	11.1		168.8	16.2		73.5	10.6		113.1	10.9	
4, 6 a.m.	161.4		3.6	173.6		4.8	77.1		3.6	116.2		3.1
6 p.m.	177.7	16.3		186.6	13.0		87.3	10.2		128.6	12.4	
5, 6 a.m.	185.5		7.8	193.4		6.8	92.9		5.6	134.0		5.4
6 p.m.	203.4	17.9		205.5	12.1		105.8	12.9		147.0	13.0	
6, 6 a.m.	214.7		11.3	212.5		7.0	114.4		8.6	155.7		8.7
6 p.m.	230.7	16.0		219.7	7.2		127.0	12.6		167.8	12.1	
7, 6 a.m.	244.1		13.4	225.4		5.7	138.9		11.9	179.5		11.7
6 p.m.	260.2	16.1		228.2	2.8		(cut)			192.6	13.1	
8, 6 a.m.	269.5		9.3	229.8		1.6				201.9		9.3
6 p.m.	288.0	18.5		—	—					220.3	18.4	
9, 6 a.m.	294.2		6.2	—		—				229.0		8.7
6 p.m.	308.5	14.3		—	—					244.0	15.0	
10, 6 a.m.	312.5		4.0	—		—				251.3		7.3
6 p.m.	329.2	16.7		—	—					271.8	20.5	
11, 6 a.m.	336.8		7.6	—		—				283.1		11.3
6 p.m.	344.4	[7.6]		—	—					291.5	[8.4]	
12, 6 a.m.	—		—	—		—				—		—
6 p.m.	352.2	—		—	—					292.0	—	
13, 6 a.m.	—		—	—		—				—		—
6 p.m.	361.8	—		—	—					298.7	—	
Totals		203.5	119.7		133.4	81.9		74.4	54.0		169.2	105.4

* Injured, causing temporary check.

Of a total increment of 3501.5 cm. gained by these shoots together, 2138.5 cm., or 61.0 per cent, was gained during daylight. The average gain per day by daylight was 8.9 cm., by night 5.6, an average daily oscillation of 3.3 cm. All shoots without exception grew faster by day than by night and the ratio is respectively 1.5:1.0. The largest gain made by any shoot in one day was that registered by no. 14 on May 10 when the morning's growth was 1.52 cm., the afternoon's 20.8 cm., and the night's 18.4 cm., making a total for the twenty-four hours of 54.4 cm. It is a remarkable fact that the proportion of the day's growth accomplished by each of the sixteen shoots during the daylight hours, 6 a.m. to 6 p.m., varied only in amount between 60 per cent and 63 per cent with the single exception of 58 per cent in one case.

TABLE 1 (Continued)

Measurements, in centimeters, of shoots of Phyllostachys nigra from April 22 to May 13, 1920, with special reference to day and night growth

DATE	11			12			13			14		
	HEIGHT	DAY GAIN	NIGHT GAIN	HEIGHT	DAY GAIN	NIGHT GAIN	HEIGHT	DAY GAIN	NIGHT GAIN	HEIGHT	DAY GAIN	NIGHT GAIN
April												
22, 6 p.m.	—	—		—	—		—	—		—	—	
23, 6 a.m.	—		—	—		—	—		—	—		—
6 p.m.	4.8	—		—	—		—	—		—	—	
24, 6 a.m.	6.0		[1.2]	15.1		—	6.8		—	—		—
6 p.m.	8.0	2.0		16.7	1.6		9.6	2.8		11.0	—	
25, 6 a.m.	9.5		1.5	19.2		2.5	11.1		1.5	12.5		[1.5]
6 p.m.	11.6	2.1		23.2	4.0		12.7	1.6		15.1	2.6	
26, 6 a.m.	13.0		1.4	25.7		2.5	14.4		1.7	17.3		2.2
6 p.m.	15.6	2.6		30.9	5.2		16.3	1.9		19.6	2.3	
27, 6 a.m.	17.5		1.9	34.3		3.4	18.0		1.7	22.0		2.4
6 p.m.	20.0	2.5		39.3	5.0		20.4	2.4		24.4	2.4	
28, 6 a.m.	22.3		2.3	43.5		4.2	22.8		2.4	27.2		2.8
6 p.m.	26.8	4.5		51.7	8.2		27.0	4.2		32.0	4.8	
29, 6 a.m.	30.2		3.4	57.5		5.8	30.4		3.4	36.5		4.5
6 p.m.	36.7	6.5		68.1	10.6		36.9	6.5		44.8	8.3	
30, 6 a.m.	40.6		3.9	73.8		5.7	41.1		4.2	50.1		5.3
6 p.m.	46.7	6.1		84.0	10.2		47.5	6.4		59.2	9.1	
May												
1, 6 a.m.	52.1		5.4	91.0		7.0	53.2		5.7	67.0		7.8
6 p.m.	61.6	9.5		108.6	17.6		(cut)			83.0	16.0	
2, 6 a.m.	69.2		7.6	119.1		10.5				94.0		11.0
6 p.m.	81.0	11.8		135.4	16.3					111.7	17.7	
3, 6 a.m.	90.0		9.0	148.1		12.7				124.3		12.6
6 p.m.	101.2	11.2		163.2	15.1					141.3	17.0	
4, 6 a.m.	106.2		5.0	169.6		6.4				146.5		5.2
6 p.m.	117.8	11.6		184.5	14.9					163.2	16.7	
5, 6 a.m.	123.2		5.4	191.8		7.3				171.6		8.4
6 p.m.	135.3	12.1		206.4	14.6					187.5	15.9	
6, 6 a.m.	145.0		9.7	217.2		10.8				200.5		13.0
6 p.m.	158.2	13.2		230.5	13.3					218.1	17.6	
7, 6 a.m.	170.4		12.2	242.2		11.7				233.6		15.5
6 p.m.	183.1	12.7		255.2	13.0					251.3	17.7	
8, 6 a.m.	192.4		9.3	262.2		7.0				263.6		12.3
6 p.m.	210.1	17.7		274.7	12.5					285.0	21.4	
9, 6 a.m.	218.0		7.9	280.0		5.3				298.2		13.2
6 p.m.	231.5	13.5		288.2	8.2					320.0	21.8	
10, 6 a.m.	238.0		6.5	292.7		4.5				330.8		10.8
6 p.m.	259.2	21.2		302.6	9.9					366.8	36.0	
11, 6 a.m.	264.5		5.3	308.5		5.9				385.2		18.4
6 p.m.	273.3	[8.8]		312.1	[3.6]					406.3	[21.1]	
12, 6 a.m.	—		—	—		—				—		—
6 p.m.	282.1	—		315.0	—					429.0	—	
13, 6 a.m.	—		—	—		—				—		—
6 p.m.	293.1	—		317.8	—					461.0	—	
Totals		160.8	97.7		180.2	113.2		25.8	20.6		227.3	145.4

The daily rise and fall of the growth-rate is represented by the curves of the sample shoots in figure 1. Every day shows a peak and every night a valley in these curves. A glance at the measurements of the shoots not figured by the curves will show that these follow a similar trend. The curves all synchronize in respect to rising growth-rate in the day and falling growth-rate in the night. Moreover, in the unusual degree of elevation or depression at irregular intervals there is general agreement. For example, when on May 1 the growth-rate of shoot no. 1 rises sharply we find that no. 3, 6, and 7 do the same. A marked depression in the curves in the early morning of May 4 is apparent in all of the curves. A consistently high level is maintained by all the curves on May 6 and 7. A sharp fall occurs in all of the curves on the night of May 9, which is followed the next

TABLE 1 (Continued)

Measurements, in centimeters, of shoots of Phyllostachys nigra from April 22 to May 13, 1929, with special reference to day and night growth

DATE	15			16			17			18		
	HEIGHT	DAY GAIN	NIGHT GAIN	HEIGHT	DAY GAIN	NIGHT GAIN	HEIGHT	DAY GAIN	NIGHT GAIN	HEIGHT	DAY GAIN	NIGHT GAIN
April												
22, 6 p.m.	—	—		—	—		—	—		—	—	
23, 6 a.m.	—		—	—		—	—		—	—		—
6 p.m.	—	—		—	—		—	—		—	—	
24, 6 a.m.	—		—	—		—	—		—	—		—
6 p.m.	8.3	—		7.0	—		6.8	—		5.3	—	
25, 6 a.m.	9.5		[1.2]	7.8		[0.8]	7.7		[0.9]	6.3		[1.0]
6 p.m.	11.4	1.9		9.0	1.2		9.2	1.5		7.3	1.0	
26, 6 a.m.	12.5		1.1	9.7		0.7	10.1		0.9	8.2		0.9
6 p.m.	13.6	1.1		11.2	1.5		11.3	1.2		9.3	1.1	
27, 6 a.m.	16.0		2.4	12.3		1.1	12.5		1.2	10.5		1.2
6 p.m.	17.7	1.7		13.5	1.2		13.5	1.0		11.4	0.9	
28, 6 a.m.	19.3		1.6	14.6		1.1	14.6		1.1	12.4		1.0
6 p.m.	22.5	3.2		16.8	2.2		16.5	1.9		14.2	1.8	
29, 6 a.m.	25.3		2.8	19.0		2.2	18.1		1.6	15.2		1.0
6 p.m.	30.0	4.7		21.8	2.8		20.5	2.4		17.9	2.7	
30, 6 a.m.	33.6		3.6	24.2		2.4	22.5		2.0	19.6		1.7
6 p.m.	39.1	5.5		27.8	3.6		25.0	2.5		21.6	2.0	
May												
1, 6 a.m.	43.5		4.4	31.7		3.9	28.0		3.0	24.5		2.9
6 p.m.	53.7	10.2		39.2	7.5		34.2	6.2		29.7	5.2	
2, 6 a.m.	61.0		7.3	45.3		6.1	39.3		5.1	34.1		4.4
6 p.m.	72.6	11.6		54.9	9.6		47.7	8.4		41.5	7.4	
3, 6 a.m.	81.5		8.9	63.2		8.3	54.5		6.8	47.5		6.0
6 p.m.	92.9	11.4		73.8	10.6		63.3	8.8		55.8	8.3	
4, 6 a.m.	97.0		4.1	77.6		3.8	67.3		4.0	58.9		3.1
6 p.m.	107.8	10.8		87.9	10.3		76.6	9.3		67.6	8.7	
5, 6 a.m.	114.3		6.5	93.5		5.6	82.1		5.5	72.3		4.7
6 p.m.	124.3	10.0		106.7	13.2		93.3	11.2		82.8	10.5	
6, 6 a.m.	131.5		7.2	115.5		8.8	102.1		8.8	90.2		7.4
6 p.m.	142.5	11.0		127.5	12.0		113.6	11.5		98.4	8.2	
7, 6 a.m.	155.7		13.2	136.2		8.7	124.0		10.4	106.3		7.9
6 p.m.	168.4	12.7		150.1	13.9		138.8	14.8		117.2	10.9	
8, 6 a.m.	177.1		8.7	159.4		9.3	140.1		1.3	123.7		6.5
6 p.m.	191.4	14.3		173.6	14.2		154.6	14.5		137.0	13.3	
9, 6 a.m.	200.5		9.1	183.1		9.5	163.5		8.9	144.2		7.2
6 p.m.	216.8	16.3		195.5	12.4		175.0	11.5		(cut)		
10, 6 a.m.	222.0		5.2	203.8		8.3	182.1		7.1			
6 p.m.	—	—		228.0	24.2		204.7	22.6				
11, 6 a.m.	—		—	242.7		14.7	220.8		16.1			
6 p.m.	—	—		260.0	[17.3]		236.6	[15.8]				
12, 6 a.m.	—		—	—		—	—		—			
6 p.m.	—	—		280.2	—		259.8	—				
13, 6 a.m.	—		—	—		—	—		—			
6 p.m.	—	—		313.2	—		291.6	—				
Totals		127.4	86.1		140.4	94.5		129.3	83.8		82.0	55.9

day by an equally marked rise of the growth-rate, which in two cases was the maximum rate reached by those shoots.

I shall now take up the observations of the periodical growth during the daylight hours, 6 a.m. to 6 p.m. Figure 2 shows the increment curves of sample shoots, no. 1, 3, 5, and 6, plotted for the days May 1 to 11 together with the curves showing the climatic record for the period stated. Of the 133 sets of figures for morning and afternoon growth, 118, or 88.7 per cent, exhibit predominance of afternoon growth, 13 greater forenoon growth, and 2 were ties. A total increment of 1774.8 cm. was gained in the daytime for the ten days. Of this amount 1033.4 cm., or 58.5 per cent, was gained in the afternoon hours, 12 noon to 6 p.m., and 741.4 cm. in the morning. The average morning gain per day was 5.5 cm., the average

afternoon gain was 7.7 cm., an average daily oscillation of 2.2 cm. for the ten days of measurement. As in the former case the range of difference in the proportion of afternoon predominance in growth is small, being from 57 per cent to 62 per cent with the exception of one afternoon which registered only 55.5 per cent of the day's growth. The total afternoon growth of each shoot without exception was greater than the total forenoon growth. The ratio of total afternoon to total forenoon growth is 1.4:1.

Growth in relation to climatic conditions. By comparing the periodical fluctuations of the normal daily temperature and relative humidity with those of the daily growth-rates, I find unmistakable correlation. I have pointed out that irregularities and modifications of the normal daily oscillation of growth-rate occur. A study of the growth increase represented by the growth curves in figure 1 shows that these irregularities synchronize. Thus on May 1 the unusual rise in temperature by four o'clock in the afternoon to 25.3° (which was probably higher an hour or so earlier) together with a drop in humidity to 60 per cent was accompanied by a very obvious rise in all of the curves simultaneously. Conversely, the very low drop in temperature to 9.5° on the night of May 3 with a medium humidity was accompanied by a slump in the growth-rates of all the shoots, not only of the sample shoots represented by the curves, but also of those other shoots whose measurements are recorded in table 1. This same reaction may be observed also on the night of May 9. The consistently high level maintained by the temperature on the nights of May 5 and 6 regardless of varying conditions of atmospheric moisture synchronize with relatively high rates of growth on those nights. During the daylight hours of May 9, despite a humidity that registered higher than usual, the low rate of increase was accompanied by a low temperature.

I find with respect to periodical fluctuations in the growth-rate during daylight the same correlation with climatic changes. By referring to figure 2 this connection can be readily perceived. Without exception the temperature at four in the afternoon registered higher than at nine in the morning every day. With only three exceptions the sample curves all possess an upward slant in the daylight columns. This indicates an increase in growth-rate during the hours 6 a.m. to 6 p.m. every day. The synchronism in the rise and fall of the growth-rate is marked in curves of the sample shoots especially from 4 p.m. on May 5 to 9 a.m. on May 9. On May 5 there was less than a degree's difference in temperature between the morning and afternoon readings. The gains of the sample shoots for the morning and afternoon period reflect this stable condition in their individual reactions, which lack any evidence of uniformity. A sharp rise in temperature from morning to afternoon on May 6 in the presence of a uniformly high hu-

midity with rain is accompanied, on the other hand, by a very uniform increase in growth-rate during daylight. A similar conformity of response

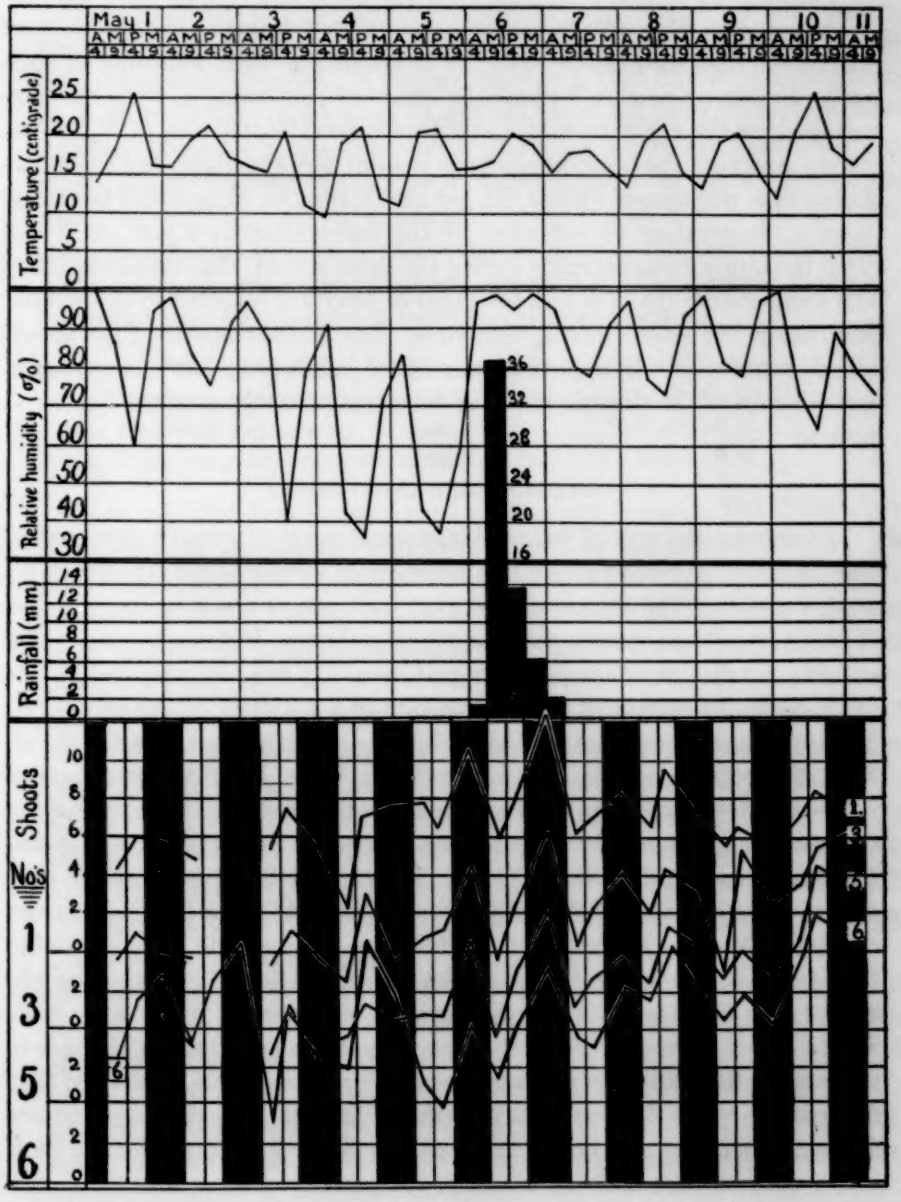

Fig. 2. Shoots 1, 3, 5, and 6 of *Phyllostachys nigra*. The curves of forenoon, afternoon, and night growth, together with those of temperature, relative humidity, and rainfall for ten days, May 1–11. Black columns signify night.

may be observed during the daytime, on May 8 and 10, under similar circumstances, but with falling humidity and no rain. It is notable that on five days, May 3, 4, 8, 9, and 10, with two exceptions (shoot no. 1 on May 4 and no. 3 on May 10), the sample shoots grew faster in the six hours of afternoon than during the whole 12 hours of the night following in each case. In this connection it should be observed that owing to wind the temperature on the nights of May 3 and 4 went down to 9.5° and 11.5°, respectively, and that the humidity in both the day and the night, but especially in the day, was unusually low (36 per cent); that on May 8 and 10 the excessive temperature as indicated by the registration at 4 p.m. coincided with the larger gains accruing during the same period, that the lower fall of the temperature (to 12.6°) on the night of May 9 is reflected in the smaller increase of the shoots during that time. The measurements of the shoots whose curves do not appear in the figure exhibit the same response in growth-rate to the climatic factor of temperature as those whose curves do appear.

DISCUSSION AND CONCLUSIONS

In seeking for special causes for unusual rates of growth observed to have occurred simultaneously in a majority of shoots at definite times, we are inevitably led to the conclusion that such causes are to be found in the climatic conditions surrounding the growing shoots. If it can be shown that unusual conditions of temperature and humidity are accompanied by the same degree of change in the growth-rate of a majority of the shoots, we have evidence of correlation. The problem is to distinguish between the effects of separate climatic factors. To determine which of the two factors, temperature or humidity, most affects the rate of elongation, an analysis of each case of apparent effect must be undertaken. Under the fairly constant conditions described by Kraus (1895) in Java, individual peculiarities were sure to become evident, while in Ceylon (Lock, 1904) with the temperature constant, the effects of varying conditions of atmospheric moisture would tend to show. Lock (1904) found that the fluctuation of growth-rates observed from Shibata's (1900) measurements of shoots of *Phyllostachys mitis* A. & C. Riv. were due rather to temperature changes than to changes in the relative humidity. In a former paper (Porterfield, 1927) I showed that fluctuations in the daily rates of growth at Shanghai were due to variations of the temperature and not to those of humidity. I maintain on the basis of my observations that the effects of temperature fluctuations are to the same degree evident in the daily oscillations of growth-rate regardless of variations in conditions of atmospheric moisture, and that for this reason temperature can be considered the climatic factor which more than any

other governs the rate of growth of *Phyllostachys nigra* shoots, if not bamboo shoots generally, growing in the Shanghai area of China.

In the early part of the grand period of growth the rate of increase is very slow and the day-to-day fluctuations are very slight. As time passes, however, the daily growth-rates become more rapid and the periodical oscillations more pronounced. It follows, therefore, that any modifications toward more or less rapid rates of growth show up proportionately more clearly. When such modifications of the growth-rate are manifest in all shoots simultaneously, the fact becomes significant. In figure 1 the normal curves of daily growth show unusual deviations at certain points. The same may be said of figure 2 where the day gain in contrast to the night is divided into forenoon and afternoon increments. The unusual deviations in figure 1 may be arranged in four categories as follows:

1. Maximum gains during daylight.....April 29, May 1, 8, 10.
2. Minimum gains during daylight.....April 30, May 9.
3. Maximum gains during the night.....May 1, 5, 6.
4. Minimum gains during the night.....May 3, 8, 9.

Not only the shoots represented by the sample curves but those whose measurements are contained in table 1 exhibit the same behavior. The high temperature (19.3°) registered at 9 a.m., April 29, in contrast to that recorded on either the day before or the day after at the same time, suggests (despite an afternoon temperature slightly lower than those of the two other days mentioned) that from noon to one o'clock, because it was sunny, the temperature rose to a higher level than that indicated by the curve; so the same reasoning may be applied here as to the other cases, that the higher temperature caused the more rapid elongation of the shoots. Hence the rise in the growth curves on that day. Concerning the second category a word of explanation is needed. A low morning temperature on April 30, because of cloudiness, brought down the mean for the day and the growth-rates came down also, in spite of optimum moisture conditions. There is no reason for believing that the temperature went up much more than is indicated by the curve, as was the case on the preceding day. All the other dates mentioned show clear agreement between the rate of elongation and the temperature variations. High mean temperatures for the night as well as for the day are reflected in the relatively high rates of growth for both periods, while low degrees of temperature, on the other hand, are seen to cause a decrease in the rate of elongation in spite of varying conditions of atmospheric moisture.

In a similar way the unusual gains in forenoon and afternoon may be assembled in four categories:

1. Maximum morning gains.....May 8 and 10.
2. Minimum morning gains.....May 3 and 6.
3. Maximum afternoon gains.....May 3, 4, 8, 10.
4. Minimum afternoon gains.....May 5 and 7.

May 8 and 10 appear in categories 1 and 3 owing to the fact that both days were sunny, as a result of which the temperature started to climb from sunrise, while on the other hand the 9th was cloudy. The effect of the temperature on the growth-rates may be read in their rise in the former case and their fall in the latter. The contrast between the morning and afternoon temperatures on May 3 and 6 and their resultant effect on the growth-rates is obvious. It is noteworthy that in spite of the very contrasting conditions of moisture the reactions of the growth-rates which paralleled the temperatures on the two days are similar. It should clearly be pointed out with regard to the third category that on the dates mentioned the afternoon gain was greater than that of the whole twelve hours of night in each case. It may also be mentioned that on the afternoon of May 9 the rate of growth registered higher than that of the following night chiefly by reason of the fact that during the night a low temperature prevailed which severely checked growth for that period; hence this date is not included. Nevertheless, the parallelism between the high level of the temperature and the high rate of elongation is marked. On May 5 and 7 the afternoon gains were low because on the both occasions it was cloudy. On the 5th we have an instance of nearly constant temperature conditions for the twelve hours of daylight (20.7°–21.3°C) with the relative humidity sinking very low (43–38 per cent). The net result was that the rate of growth was checked, in some cases, causing it to fall below the rate of the morning. In other words, although there were optimum temperature conditions, they were constant, so that variations in other factors, in this case humidity, had a noticeable effect on the rate of elongation. This approximates Lock's (1904) experience with the giant bamboo *Dendrocalamus* in Ceylon.

The purpose of classifying the periods of unusually large or small gains in both problems is to show that temperature may not only stimulate higher rates of growth at certain times of the day, but may also have a retarding effect, and that both effects may occur at any time; that while high degrees of temperature seem to induce higher rates of growth, low temperatures seem to have a reducing effect on these rates. The evidence as a whole, after comparing individual cases, both within and without similar categories, and after analyzing carefully each class of circumstances, points toward the definite conclusion that temperature is the dominating climatic factor governing the growth of *Phyllostachys nigra* shoots in Shanghai. Notwithstanding the high transpiration during the sunny hours of day-

light, the diurnal rise of temperature which reaches its peak usually after noon seems to have induced an accelerated growth-rate, while at night, despite the optimum conditions of atmospheric humidity, the growth-rate slows down with the drop in temperature.

Because of my emphasis on temperature, it should not, however, be thought that moisture is claimed to be of no importance in the growth of bamboo shoots. It is, on the other hand, the conditioning factor of its distribution. Without moisture bamboos cannot exist, and even the spread of varieties occupying inland altitudes follows the line of available moisture. This means that, given an average humidity of saturation 75–80 per cent with temperature fluctuations above 7°C., the existence of bamboos is assured, but that from this point during active growth temperature is the chief governing factor. Precipitations and varying conditions of atmospheric moisture beyond the conditioning point seem not to have had any influence on the rate of growth except occasionally as a check because of the cooling effect when rain fell. Certainly the present evidence does not show anything like the parallelism of growth-rate with the relative humidity that Lock found in his studies of the hourly growth of *Dendrocalamus* with relation to conditions of moisture and temperature at Peradeniya, Ceylon, but it does, on the other hand, show close agreement at any time between the rates of growth and temperature. I, therefore, conclude, not only from the present evidence but from that published by me previously (Porterfield, 1927, 1928) with regard to the factor having the most effect during the grand period of growth, that the rate of elongation of *Phyllostachys nigra* shoots in Shanghai, including variations of the normal periodicity of growth, daily and diurnal, is affected most by fluctuations of temperature, irrespective of variations in moisture conditions.

SUMMARY

1. Eighteen shoots of *Phyllostachys nigra* were measured at St. John's University, Shanghai, China, from April 22 to May 1, 1929, twice daily, at 6 a.m. and at 6 p.m., and from May 1 to 11 three times a day, at 6 a.m., at 12 noon, and at 6 p.m. All measurements ceased on May 13.

2. Elongation in all shoots took place more rapidly during the day than during the night, the ratio being approximately 1.5:1.0. Of the 240 sets of figures representing the day and night gains for sixteen shoots, 211, or 87.5 per cent, exhibit greater daylight growth, 23 greater night growth, and 6 the same amount during both times. Of the total increment of 3501.5 cm. gained by these shoots together, 2138.5 cm., or 61 per cent, were gained during daylight. The average gain per day for the grand period was 8.9 cm. by day and 5.6 cm. by night. The largest gain recorded was 54.4 cm. for

24 hours, by shoot 14 on May 10, 36 cm. of which represents the daytime increase and 18.4 cm. that of the night.

3. During the daylight hours 6 a.m. to 6 p.m. elongation was most rapid in all shoots in the afternoon, the ratio being 1.4:1.0. Of the 133 sets of figures for morning and afternoon growth 118, or 88.7 per cent, exhibit greater afternoon growth, 13 greater forenoon growth, and 2 the same for both afternoon and morning. Of the total increment of 1774.8 cm. gained by the sixteen shoots together in ten days, 1033.4 cm., or 58.5 per cent, were gained in the afternoon hours 12 noon to 6 p.m. and 741.4 cm. in the morning hours 6 a.m. to 12 noon. The average morning gain per day for the ten days, May 1 to 11, was 5.5 cm. and that of the afternoon 7.7 cm. The largest single increase in the morning and afternoon was registered by shoot 14 on May 10 when the morning growth was 15.2 cm. and that of the afternoon 20.8 cm.

4. The periodical fluctuations of temperature and relative humidity were noted and were found to be variable, depending on sunlight, wind, and rain. Records of temperature and relative humidity taken four times a day, 4 and 9 a.m. and 4 and 9 p.m., revealed the fact that the temperature daily varied inversely as the relative humidity, that the high register of the day for temperature was generally at 4 p.m. with the relative humidity reaching its lowest, and that the low point of the temperature was reached at 4 a.m. when the relative humidity was highest. The average daily range for temperature was from 22°C. at 4 p.m. to 14° at 4 a.m., while for the corresponding times the relative humidity ranged from 60 to 93 per cent, respectively. There were five rainy periods, April 25–26, 27–28, 30, May 6–7, and May 11–13, of which the second and third periods were the least rainy. The largest precipitation came on May 6 when altogether 59.12 mm. of rain fell.

5. The sample curves of shoots 1, 3, 6, and 7 plotted in figure 1 show synchronic variations with the curve of temperature above and beyond normal periodicity. From the evidence high temperature during the day regardless of moisture conditions brings about an increase in rate of elongation, while a low temperature checks it. At night a higher temperature than usual is at once reflected in a larger increase in height of the shoots, while the reverse effect is observed with low temperatures.

6. The sample curves of shoots 1, 3, 5, and 6 in figure 2 corroborate the evidence brought out in figure 1. The cause of unusual morning and afternoon gains is to be looked for in the higher degrees of temperature existing at those times. Relatively small gains, on the other hand, even though optimum conditions of moisture prevail, are to be referred to low tempera-

ture. The close agreements between the temperature and growth curves as to general behavior warrant this assumption.

7. The measurements of the shoots contained in tables 1 and 2, but not represented in the figures, furnish additional corroboration of the principle that temperature affects growth-rate more than any other factor, and together they support the general proposition that with rising temperature the rate of elongation increases, with falling temperature it decreases regardless of the moisture conditions.

St. John's University
Shanghai, China

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TABLE 2

Measurements, in centimeters, of shoots of Phyllostachys nigra from May 1 to May 11, 1929, with special reference to morning and afternoon growth

DATE	1				2				3				5			
	HEIGHT	DAY GAIN		NIGHT GAIN	HEIGHT	DAY GAIN		NIGHT GAIN	HEIGHT	DAY GAIN		NIGHT GAIN	HEIGHT	DAY GAIN		NIGHT GAIN
		A.M.	P.M.			A.M.	P.M.			A.M.	P.M.			A.M.	P.M.	
May																
1, 6 a.m.	39.3				21.7				33.0				21.7			
12 noon	43.6	4.3			—	—			36.7	3.7			—	—		
6 p.m.	49.6		6.0		26.6		—		41.7		5.0		27.7		—	
2, 6 a.m.	54.5			4.9	30.0			3.4	45.7			4.0	32.1			4.4
12 noon	59.3	[4.8]			—	—			49.5	[3.8]			35.2	[3.1]		
6 p.m.			—		—		—		—		—		—		—	
3, 6 a.m.	73.7			—	38.5			—	58.4			—	45.7			—
12 noon	79.2	5.5			—	—			61.8	3.4			48.5	2.8		
6 p m.	86.9		7.7		43.0		—		66.8		5.0		53.6		5.1	
4, 6 a.m.	92.5			5.6	45.0			2.0	70.5			3.7	56.8			3.2
12 noon	94.6	2.1			—	—			73.4	2.9			60.5	3.7		
6 p.m.	101.7		7.1		50.5		—		80.4		7.0		65.9		5.4	
5, 6 a.m.	109.1			7.4	53.5			3.0	84.1			3.7	70.5			4.6
12 noon	116.9	7.8			—	—			88.8	4.7			75.4	4.9		
6 p.m.	123.5		6.6		58.6		—		93.9		5.1		80.3		4.9	
6, 6 a.m.	134.2			10.7	63.6			5.0	102.5			8.6	89.0			8.7
12 noon	140.2	6.0			64.0	1.4			106.3	3.8			92.8	3.8		
6 p.m.	148.3		8.1		69.7		5.7		112.8		6.5		99.8		7.0	
7, 6 a.m.	160.8			12.5	74.2			4.5	123.3			10.5	109.8			10.0
12 noon	167.0	6.2			76.8	2.6			127.8	4.5			115.5	5.7		
6 p.m.	174.0		7.0		78.3		1.5		133.9		6.1		122.0		6.5	
8, 6 a.m.	182.5			8.5	81.1			2.8	142.0			8.1	129.9			7.9
12 noon	189.4	6.9			83.0	1.9			148.0	6.0			136.5	6.6		
6 p.m.	198.8		9.4		86.0		3.0		156.4		8.4		145.8		9.3	
9, 6 a.m.	206.2			7.4	88.2			2.2	163.8			7.4	154.1			8.3
12 noon	212.0	5.8			90.1	1.9			167.0	3.2			161.0	6.9		
6 p.m.	218.5		6.5		92.5		2.4		176.5		9.5		169.0		8.0	
10, 6 a.m.	224.1			5.6	—			—	183.3			6.8	175.9			6.9
12 noon	231.2	7.1			—	—			190.8	7.5			184.7	8.8		
6 p.m.	239.7		8.5		—		—		200.4		9.6		197.3		12.6	
11, 6 a.m.	247.0			7.3	—			—	210.5			10.1	209.0			11.7
Totals		51.7	64.9			7.8	12.6			39.7	62.2			43.2	58.8	

[—] unpaired or odd measurement; therefore not included in totals.

TABLE 2 (Continued)

TABLE 2 (Continued)

Measurements, in centimeters, of shoots of Phyllostachys nogra from May 1 to May 11, 1929, with special reference to morning and afternoon growth

DATE	6				7				8				9			
	HEIGHT	DAY GAIN		NIGHT GAIN	HEIGHT	DAY GAIN		NIGHT GAIN	HEIGHT	DAY GAIN		NIGHT GAIN	HEIGHT	DAY GAIN		NIGHT GAIN
		A.M.	P.M.			A.M.	P.M.			A.M.	P.M.			A.M.	P.M.	
May																
1, 6 a.m.	81.2				90.5				91.3				32.6			
12 noon	88.0	6.8			97.1	6.6			98.0	6.7			35.6	3.0		
6 p.m.	97.9		9.9		107.1		10.0		108.2		10.2		40.2		4.6	
2, 6 a.m.	108.8			10.9	117.8			10.7	120.8			12.6	46.1			5.9
12 noon	116.0	7.2			124.5	6.7			128.5	7.7			49.7	3.6		
6 p.m.	126.6		10.6		132.1		7.6		139.8		11.3		55.7		6.0	
3, 6 a.m.	139.2			12.6	146.7			14.6	152.6			12.8	62.9			7.2
12 noon	142.2	3.0			149.0	2.3			160.8	8.2			67.4	4.5		
6 p.m.	151.3		9.1		157.8		8.8		168.8		8.0		73.5		6.1	
4, 6 a.m.	156.6			5.3	161.4			3.6	173.6			4.8	77.1			3.6
12 noon	162.6	6.0			168.5	7.1			178.6	5.0			81.4	4.3		
6 p.m.	175.3		12.7		177.7		9.2		186.6		8.0		87.3		5.9	
5, 6 a.m.	185.2			9.9	185.5			7.8	193.4			6.8	92.9			5.6
12 noon	190.5	5.3			193.5	8.0			199.0	5.6			98.8	5.9		
6 p.m.	194.4		3.9		203.4		9.9		205.5		6.5		105.8		7.0	
6, 6 a.m.	202.6			8.2	214.7			11.3	212.5			7.0	114.4			8.6
12 noon	208.1	5.5			220.8	6.1			215.7	3.2			119.9	5.5		
6 p.m.	216.2		8.1		230.7		9.9		219.7		4.0		127.0		7.1	
7, 6 a.m.	227.6			11.4	244.1			13.4	225.4			5.7	138.9			11.9
12 noon	235.4	7.8			252.0	7.9			226.7	1.3			144.9	[6.0]		
6 p.m.	242.5		7.1		260.2		8.2		228.2		1.5		—		—	
8, 6 a.m.	252.7			10.2	269.5			9.3	229.8			1.6	—			—
12 noon	262.5	9.8			277.7	8.2			—	—			—	—		
6 p.m.	274.6		12.1		288.0		10.3		—		—		—		—	
9, 6 a.m.	284.9			10.3	294.2			6.2	—			—	—			—
12 noon	293.7	8.8			301.6	7.4			—	—			—	—		
6 p.m.	303.6		9.9		308.5		6.9		—		—		—		—	
10, 6 a.m.	312.2			8.6	312.5			4.0	—			—	—			—
12 noon	324.1	11.9			320.5	8.0			—	—			—	—		
6 p.m.	338.0		13.9		329.2		8.7		—		—		—		—	
11, 6 a.m.	351.0			13.0	336.8			7.6	—			—	—			—
Totals		72.1	104.4			68.3	89.5			37.7	49.5			26.8	36.7	

[—] unpaired or odd measurement; therefore not included in totals.

TABLE 2 (Continued)

Measurements, in centimeters, of shoots of Phyllostachys nigra from May 1 to May 11, 1929, with special reference to morning and afternoon growth

DATE	10				11				12				14			
	HEIGHT	DAY GAIN		NIGHT GAIN	HEIGHT	DAY GAIN		NIGHT GAIN	HEIGHT	DAY GAIN		NIGHT GAIN	HEIGHT	DAY GAIN		NIGHT GAIN
		A.M.	P.M.			A.M.	P.M.			A.M.	P.M.			A.M.	P.M.	
May																
1, 6 a.m.	63.9				52.1				91.0				67.0			
12 noon	68.9	5.0			56.7	4.6			96.2	5.2			73.5	6.5		
6 p.m.	76.0		7.1		61.6		4.9		108.6		12.4		83.0		9.5	
2, 6 a.m.	83.1			7.1	69.2			7.6	119.1			10.5	94.0			11.0
12 noon	88.0	4.9			73.7	4.5			125.2	6.1			101.2	7.2		
6 p.m.	93.1		5.1		81.0		7.3		135.4		10.2		111.7		10.5	
3, 6 a.m.	102.2			9.1	90.0			9.0	148.1			12.7	124.3			12.6
12 noon	105.4	3.2			95.7	5.7			156.2	8.1			131.8	7.5		
6 p.m.	113.1		7.7		101.2		5.5		163.2		7.0		141.3		9.5	
4, 6 a.m.	116.2			3.1	106.2			5.0	169.6			6.4	146.5			5.2
12 noon	122.4	6.2			109.4	3.2			176.9	7.3			153.2	6.7		
6 p.m.	128.6		6.2		117.8		8.4		184.5		7.6		163.2		10.0	
5, 6 a.m.	134.0			5.4	123.2			5.4	191.8			7.3	171.6			8.4
12 noon	139.6	5.6			129.3	6.1			198.1	7.3			176.5	4.9		
6 p.m.	147.0		7.4		135.3		6.0		206.4		8.3		187.5		11.0	
6, 6 a.m.	155.7			8.7	145.0			9.7	217.2			10.8	200.5			13.0
12 noon	160.5	4.8			150.5	5.5			222.7	5.5			208.4	7.9		
6 p.m.	167.8		7.3		158.2		7.7		230.5		7.8		218.1		9.7	
7, 6 a.m.	179.5			11.7	170.4			12.2	242.2			11.7	233.6			15.5
12 noon	186.2	6.7			176.4	6.0			248.5	6.3			242.5	8.9		
6 p.m.	192.6		6.4		183.1		6.7		255.2		6.7		251.3		8.8	
8, 6 a.m.	201.9			9.3	192.4			9.3	262.2			7.0	263.6			12.3
12 noon	210.1	8.2			200.3	7.9			268.0	5.8			273.6	10.0		
6 p.m.	220.3		10.2		210.1		9.8		274.7		6.7		285.0		11.4	
9, 6 a.m.	229.0			8.7	218.0			7.9	280.0			5.3	298.2			13.2
12 noon	233.6	4.6			224.2	6.2			284.4	4.4			308.4	10.2		
6 p.m.	244.0		10.4		231.5		7.3		288.2		3.8		320.0		11.6	
10, 6 a.m.	251.3			7.3	238.0			6.5	292.7			4.5	330.8			10.8
12 noon	260.1	8.8			245.7	7.7			294.4	1.7			346.0	15.2		
6 p.m.	271.8		11.7		259.2		13.5		302.6		8.2		366.8		20.8	
11, 6 a.m.	283.1			11.3	264.5			5.3	308.5			5.9	385.2			18.4
Totals		58.0	79.5			57.4	77.1			57.7	78.7			85.0	112.8	

[—] unpaired or odd measurement; therefore not included in totals.

TABLE 2 (Continued)

TABLE 2 (Continued)

Measurements, in centimeters, of shoots of Phyllostachys nigra from May 1 to May 11, 1929, with special reference to morning and afternoon growth

DATE	15				16				17				18			
	HEIGHT	DAY GAIN		NIGHT GAIN	HEIGHT	DAY GAIN		NIGHT GAIN	HEIGHT	DAY GAIN		NIGHT GAIN	HEIGHT	DAY GAIN		NIGHT GAIN
		A.M.	P.M.			A.M.	P.M.			A.M.	P.M.			A.M.	P.M.	
May																
1, 6 a.m.	43.5				31.7				28.0				24.5			
12 noon	47.8	4.3			34.5	2.8			30.2	2.2			26.4	1.9		
6 p.m.	53.7		5.9		39.2		4.7		34.2		4.0		29.7		3.3	
2, 6 a.m.	61.0			7.3	45.3			6.1	39.3			5.1	34.1			4.4
12 noon	65.6	4.6			49.0	3.7			42.7	3.4			37.1	3.0		
6 p.m.	72.6		7.0		54.9		5.9		47.7		5.0		41.5		4.4	
3, 6 a.m.	81.5			8.9	63.2			8.3	54.5			6.8	47.5			6.0
12 noon	—	—			—	—			—	—			—	—		
6 p.m.	92.9		—		73.8		—		63.3		—		55.8		—	
4, 6 a.m.	97.0			4.1	77.6			3.8	67.3			4.0	58.9			3.1
12 noon	—	—			83.2	5.6			71.3	4.0			62.8	3.9		
6 p.m.	107.8		—		87.9		4.7		76.6		5.3		67.6		4.8	
5, 6 a.m.	114.3			6.5	93.5			5.6	82.1			5.5	72.3			4.7
12 noon	118.8	4.5			—	—			—	—			—	—		
6 p.m.	124.3		5.5		106.7		—		93.3		—		82.8		—	
6, 6 a.m.	131.5			7.2	115.5			8.8	102.1			8.8	90.2			7.4
12 noon	134.5	3.0			118.4	2.9			106.5	4.4			91.9	1.7		
6 p.m.	142.5		8.0		127.5		9.1		113.6		7.1		98.4		6.5	
7, 6 a.m.	155.7			13.2	136.2			8.7	124.0			10.4	106.3			7.9
12 noon	162.5	6.8			142.6	6.4			129.1	5.1			111.5	5.2		
6 p.m.	168.4		5.9		150.1		7.5		138.8		9.7		117.2		5.7	
8, 6 a.m.	177.1			8.7	159.4			9.3	140.1			1.3	123.7			6.5
12 noon	181.4	4.3			164.7	5.3			146.4	6.3			129.2	5.5		
6 p.m.	191.4		10.0		173.6		8.9		154.6		8.2		137.0		7.8	
9, 6 a.m.	200.5			9.1	183.1			9.5	163.5			8.9	144.2			7.2
12 noon	208.1	7.6			186.9	3.8			167.0	3.5			147.0	[3.0]		
6 p.m.	216.8		8.7		195.5		8.6		175.0		8.0		—		—	
10, 6 a.m.	222.0			5.2	203.8			8.3	182.1			7.1	—			—
12 noon	228.5	[6.5]			213.8	10.0			192.4	10.3			—	—		
6 p.m.	—		—		228.0		14.2		204.7		12.3		—		—	
11, 6 a.m.	—			—	242.7			14.7	—			—	—			—
Totals		35.1	51.0			40.5	63.6			39.2	59.6			21.2	32.5	

[—] unpaired or odd measurement; therefore not included in totals.

TABLE 3

The record of the climatic conditions of temperature, relative humidity, and rainfall taken four times daily during the grand period of growth of Phyllostachys nigra in 1929

DATE	TEMPERATURE (CENTIGRADE)	RELATIVE HUMIDITY	RAINFALL (MILLIMETERS)	REMARKS
April				
22, 4 a.m.	7.6	78		Mild but windy.
9	16.6	32		
4 p.m.	19.7	41		
9	13.1	74		
23, 4 a.m.	12.7	74		Sunny and warm.
9	20.0	53		
4 p.m.	26.3	44		
9	16.7	85		
24, 4 a.m.	14.2	95		Sunny and warm.
9	24.0	61		
4 p.m.	21.0	42		
9	18.7	80		
25, 4 a.m.	16.8	90		Windy; cloudy,
9	22.8	64		rain.
4 p.m.	17.7	76		
9	11.0	99	5.85	
26, 4 a.m.	12.7	92	2.54	Clearing.
9	16.7	76	0.50	
4 p.m.	22.4	43		
9	15.1	72		
27, 4 a.m.	13.7	90		Cloudy; showery.
9	19.6	63		
4 p.m.	17.9	68	0.25	
9	15.0	78		
28, 4 a.m.	13.6	95	0.25	Shower; cloudy.
9	17.5	85	0.75	bright.
4 p.m.	23.5	51		
9	17.9	80		
29, 4 a.m.	12.8	90		Sunny.
9	19.3	61		
4 p.m.	21.5	59		
9	14.5	88		
30, 4 a.m.	12.9	94		Showers; cloudy
9	16.3	89	0.50	bright; sunny.
4 p.m.	22.7	71	1.01	
9	16.1	96		
May				
1, 4 a.m.	14.5	100		Sunny and warm.
9	18.1	87		
4 p.m.	25.3	60		
9	16.3	94		
2, 4 a.m.	16.2	98		Hazy and sunny.
9	19.5	84		
4 p.m.	21.9	76		
9	17.6	92		

TABLE 3 (Continued)

The record of the climatic conditions of temperature, relative humidity, and rainfall taken four times daily during the grand period of growth of Phyllostachys nigra in 1929

DATE	TEMPERATURE (CENTIGRADE)	RELATIVE HUMIDITY	RAINFALL (MILLIMETERS)	REMARKS
May				
3, 4 a.m.	16.5	97		Cloudy; clearing, breeze.
9	15.2	88		
4 p.m.	20.6	40		
9	12.1	79		
4, 4 a.m.	9.5	91		Clear; cooler and windy.
9	19.2	42		
4 p.m.	21.7	36		
9	13.2	72		
5, 4 a.m.	11.5	84		Windy; cool and clear; then cloudy.
9	20.7	43		
4 p.m.	21.3	38		
9	16.0	59		
6, 4 a.m.	16.3	97	1.52	Rain.
9	17.2	99	37.10	
4 p.m.	20.5	95	13.90	
9	18.6	99	6.60	
7, 4 a.m.	15.2	95	2.28	Cloudy.
9	18.3	81		
4 p.m.	18.6	79		
9	16.1	91		
8, 4 a.m.	14.4	97		Sunny.
9	19.5	78		
4 p.m.	22.1	74		
9	15.4	93		
9, 4 a.m.	13.1	99		Sunny and cloudy.
9	19.2	82		
4 p.m.	20.2	79		
9	15.2	97		
10, 4 a.m.	12.6	100		Sunny and warm.
9	21.3	74		
4 p.m.	26.1	64		
9	18.1	89		
11, 4 a.m.	17.0	80		Cloudy with breeze; rainy.
9	19.3	74		
4 p.m.	18.2	86	0.10	
9	15.3	81	5.58	
12, 4 a.m.	14.6	97	3.30	Rain.
9	15.7	96	1.52	
4 p.m.	16.4	93	0.58	
9	16.2	95	1.00	
13, 4 a.m.	15.9	95	0.25	Clear.
9	21.5	61		
4 p.m.	21.8	55		
9	15.0	93		

New plants from Colorado

GEORGE E. OSTERHOUT

Juncus exilis sp. nov. A tufted perennial 10–15 cm. high, stems very slender, almost filiform; the leaves filiform and involute, some of them as long as the stems, sheaths of the leaves with rather short scarious ligules; the very slender spathe 1–4 cm. long; the inflorescence 3–5 flowered, 8–10 mm. long, or some times a single flower; perianth segments acute, 3–4 mm. long, the inner or petals broadly scarious margined, with 2 brownish veins which unite at the apex, the sepals somewhat narrower with a mid-rib; the capsule 3-valved, the length of the perianth lobes.

This species has some likeness to *Juncus confusus* Coville, but is a much smaller plant.

Collected at Steamboat Springs in Routt County, Colorado, July 11, 1913. No. *4965*.

Chenopodium deltaphyllum sp. nov. Stem 5–7 dm. high, glabrous and often reddish, branched from the base with spreading branches, the lower branches 3–4 dm. long; the whole plant sparingly leafy, with rather small delta-shaped leaves, glabrous above, slightly mealy beneath, 1–2 cm. long and about the same in width at the base, thickish and 3-nerved, obtuse, on petioles about 1 cm. long, the upper becoming lanceolate or oblanceolate; the interrupted glomerate spikes exceeding the leaves, slightly mealy; the sepals scarcely carinate, and only partially covering the seeds; the pericarp easily separating from the seeds, which are black and shining and over 1 mm. wide.

This species is somewhat related to *Chenopodium Fremontii* S. Wats., but it a stouter plant; it is less leafy and the leaves smaller and thicker; the glomerules of fruit are larger, and the seeds larger.

Collected in Estes Park, Larimer County, Colorado, along the road from the Park to Glacier Basin, Sept. 4, 1930. No. *7308*.

Pentstemon pallescens sp. nov. Subalpine, stem 4–6 dm. high, rather slender, glabrous but slightly glandular at the top; stem leaves ovate-acuminate and clasping at the base, 5–7 cm. long, about 5 pairs to the inflorescence, root leaves spatulate and petioled, glabrous; inflorescence 10–15 cm. long, paniculate and crowded at the top, the peduncles short, slightly glandular; the caylx lobes narrowly ovate, acuminate, glandular pubescent, 8–10 mm. long; the corolla whitish, but appearing yellowish in the dried specimens, 20–25 mm. long, not strongly funnelform, the tube much shorter that the throat, the lower lip bearded within, the whole corolla slightly pubescent without, the anthers glabrous and black, dehiscent for their whole length; the sterile filament with a slight tuft of yellow hairs at the tip; the capsule ovate, almost 1 cm. long.

Collected on Rabbit Ears Pass, southwest of North Park, Colorado, Aug. 5, 1930. No. *7280*.

Chrysopsis elata sp. nov. Stems one or more from a seemingly creeping rootstock, branched only near the top, slender, 6 dm. high, puberulent and with a few scattered hairs, leafy to the top, the upper leaves slightly smaller; stem leaves oblanceolate, narrowed to a sessile base or the lower ones short petioled, the upper part tapering to an apiculate point, a few ciliate hairs near the base, and a few hairs on the midrib beneath, somewhat granuliferous on both sides under a good glass; heads clustered at the top, on puberulent peduncles 3–4 cm. long and subtended by linear bracts; involucral bracts linear, glandular puberulent; achenes 3 mm. long, narrowly obovate; pappus brownish.

Collected at Red Cliff, Eagle County, Colorado, Aug. 16, 1906. No. *3335*.

Cryptantha exigua sp. nov. A small annual plant, much branched from the base, the stems about 5 cm. long, strigose with coarse stiff hairs; leafy, the leaves 5–7 mm. long, oblanceolate, about 1 mm. wide near the upper end, hispid; the calyx lobes not more than 2 mm. long, in fruit somewhat longer, covered with long straight hairs; the corolla white, slender, about 2 mm. long; the 4 nutlets narrowly ovate, 1 mm. long, light colored, all smooth, no open areola between the forks of the groove, and seemingly attached for their whole length.

This is a *Cryptantha* which I collected with specimens of *Mertensia micrantha* A. Nelson in July 1900 or July 1903, in Moraine Park, in the western part of Estes Park, Larimer County, Colorado, and overlooked until recently when I was re-examining my old collections.

I have numbered it *7339*.

OENOTHERA LACINIATA GRANDIS Britton. I collected this plant quite a number of years ago, July 1895, along the railroad bank at Palmer Lake, El Paso County. It may not grow there now, but *Oenothera laciniata* is said to be quite common in Nebraska, and probably may be found in eastern Colorado.

WINDSOR, WELD COUNTY
COLORADO

INDEX TO AMERICAN BOTANICAL LITERATURE
1928—1930

The aim of this Index is to include all current botanical literature written by Americans, published in America, or based upon American material; the word America being used in the broadest sense.

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